Original Article
http://mjiri.iums.ac.ir
Medical Journal of the Islamic Republic of Iran (MJIRI)

Med J Islam Repub Iran. 2022 (1 Feb);36.1. https://doi.org/10.47176/mjiri.36.1

Does the Extension Torque Control Differ between Injured and Uninjured Knees of ACL-Deficient Individuals?

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Received: 31 Jul 2021 Published: 1 Feb 2022

Abstract

Background: Knee extension torque control decreases after anterior cruciate ligament (ACL) rupture. There is a controversy in neuromuscular control changes on the uninvolved side. We intended to evaluate the steadiness and accuracy of quadriceps muscle control in the healthy and deficient sides of people with acute ACL rupture.

Methods: In this cross-sectional study, thirteen men with ACL rupture (age: 27.8±7.0, body mass index (BMI): 24.7±2.25: 24.7, days from injury: 48.1±21.3) participated in the study. We measured quadriceps force control, which is quantitatively assessed by the standard deviation (SD) of joint torque for a predefined submaximal target. The accuracy of muscular control or performance of quadriceps is commonly quantified by the root mean square of error (RMSE) was also measured. A two-way analysis of variance was conducted to assess SD and RMSE of two levels of quadriceps contraction (30% of muscle voluntary contraction (MVC), 50% of MVC) across both healthy and deficient knees.

Results: There was a significant main effect for SD and RMSE of MVC percentage ($p<0.001$). SD of quadriceps torque in 50% of MVC (1.44 ± 0.13) was higher than 30% of MVC (0.88 ± 0.1). In contrast, there was no significant main effect for SD and RMSE of knee condition.

Conclusion: After unilateral ACL rupture, the neuromuscular system becomes defected and quadriceps muscle control is then reduced in the healthy side. Therefore, the healthy side is also vulnerable to ligamentous damage. Besides, with the increasing intensity of physical activities, neuromuscular control decreases and the risk of re-injury rises.

Keywords: ACL Rupture, Quadriceps Force Control, Neuromuscular Control, Knee Extension Torque

Conflicts of Interest: *None declared*
Funding: *This research was partly supported by the Rehabilitation Research Center, Iran University of Medical Sciences under grant number 97-4-6-14006.*

Cite this article as: Nemati Z, Sanjari MA, Jalali M, Bagheri Fard A. Does the Extension Torque Control Differ between Injured and Uninjured Knees of ACL-Deficient Individuals?. *Med J Islam Repub Iran.* 2022 (1 Feb);36:1. https://doi.org/10.47176/mjiri.36.1

Introduction

In the unilateral anterior cruciate ligament rupture, the anterior cruciate ligament ACL's mechanoreceptors' lack of feedback disrupts the proprioception of both healthy and deficient knees (1) and causes failure of the neuromuscular system (2). In addition to reducing the control and function of the quadriceps muscle on the injured side, having a defective neuromuscular system is one of the risk factors for ligament rupture on the opposite side (3, 4). Some studies have shown that the risk of anterior cruciate ligament rupture increases on the opposite side after injury

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↑What is "already known" in this topic:
In the unilateral anterior cruciate ligament rupture, the neuromuscular system becomes defective. Quadriceps muscle's control reduces on both sides. There is controversy if the unilateral anterior cruciate ligament rupture increases the risk of ligament rupture in the healthy side.

→What this article adds:
Extension torque control was compromised in the uninvolved side of individuals with an acute ACL injury. There was a better control in activities where muscle contraction was not intense. Attention should be paid to the healthy side because defects in the neuromuscular function cause more stress on ligaments and make them injury-prone.

of one leg (5).

In many studies, the healthy side of individuals with unilateral ACL deficiency was considered to control (6, 7). However, some studies have shown that the healthy side in these individuals is also affected by injury and adapts to it (8, 9). Due to Zampeli et al. (10), this adaptation changes the walking pattern of the healthy side and makes it even more rigid than the injured side (10). However, one study has shown that displacement of the healthy tibiofemoral joint of individuals with unilateral ACL rupture is similar to that of healthy individuals (11) in an active task like gait; other studies have shown that this displacement is more in the healthy side of individuals with unilateral deficiency than healthy individuals (12) in passive tests. It is not clear if this greater displacement is the effect of the inherent laxity of the joint or is a consequence of reduced neuromuscular control. As the neuromuscular system affects the joint kinematics, in order to address the above question, we aimed to evaluate the neuromuscular control in unilateral anterior cruciate ligament rupture.

Tibiofemoral knee joint stability is provided by combining ligaments, muscle contraction forces, bony topography, and joint load (13). After the ACL rupture, the quadriceps muscle's role in controlling the stability of the knee joint becomes even more important (14). On the other hand, due to the reduction of knee proprioception, the control of quadriceps contraction is reduced and causes non-coper people to be candidates for ligament reconstruction surgery due to frequent giving-ways of the knee (15). The better the control of quadriceps muscle, the lower the risk of knee giving-way.

One method to evaluate the neuromuscular function is to measure muscle force control by its steadiness and error in submaximal contractions (16). The ability to control quadriceps muscle and improve its function is one of the most important factors in determining knee function improvement (17). Since maximum muscle contraction is not required in daily activities, submaximal muscle strength is assessed (18). While a person tries to apply a constant force, the actual force is not constant and fluctuates slightly (19). The amount of fluctuation provides valuable information about motor coordination and movement control (20). Moreover, muscle force steadiness is a parameter that researchers have used to study adaptations in neuromuscular control with injuries and interventions (21). When a person is asked to apply a force at a submaximum level and keep it constant, he/she sometimes keeps the force constant with an error from the target. So, the error from the target is another measure to quantify the muscle control. Some studies have used steadiness and some others the target error to assess quadriceps control in ACL deficient people; however, we have examined the control of joint torque from both perspectives in this study.

Steadiness is the ability to provide a constant torque for a period of time (16). In turn, this is a reflection of muscular control which could be quantitatively assessed by the standard deviation (SD) of measured joint torque for a predefined submaximal target. In this sense, SD indicates the consistency of muscle contraction; the lower the SD, the greater the steadiness or muscular control. Previous studies have shown that quadriceps muscle steadiness is lower in people with ACL rupture than healthy people (21) and they have less ability to control their muscles efficiently.

The accuracy of muscular control or muscle performance is defined as the error between the submaximal target torque and the actual recorded joint torque, which could be quantified by the root mean square of the error (RMSE) (17). The lower the RMSE value, the better the accuracy of muscular control. Perraton et al. in 2017, found that RMSE was lower in people who have undergone ACL reconstruction surgery than healthy ones (17).

In this study, we intended to evaluate the steadiness and accuracy of quadriceps muscle control in the healthy and deficient side of people with acute ACL rupture to examine the effect of injury on the neuromuscular function in both sides and also assess the potential difference between the healthy and the deficient sides. We hypothesized that the healthy side's quadriceps muscles have better control than the deficient side; by quantifying the muscular control's steadiness and error steadiness and error of the muscular control.

Methods

Participants

In this observational cross-sectional study, 13 men with acute unilateral ACL deficiency entered the study. The inclusion criteria were as follows: 1) being 18 to 40 years old , 2) having a unilateral and isolated rupture of ACL confirmed by magnetic resonance imaging (MRI) without any associated injury in bone or soft tissues, 3) the injury has happened up to three months before entering the study , 4) having had a moderate activity level before injury due to Tegner questionnaire score (22) (from 3 to 5), 5) having no history of fracture and surgery in the knee joint area , 6) having no history of ACL or other ligaments or meniscus injury, and 7) having no deformity in the lower extremity (age: 27.8±7.0, days from injury: 48.1±21.3). The Tagner questionnaire was first designed in 1985 (23) and the validity and reliability of the questionnaire for patients with anterior cruciate ligament rupture were assessed in 2009 (22). Cultural adaptation of this questionnaire in Persian was made in 2011 by Negahban et al. (24). The exclusion criteria were: 1) having knee joint pain and inflammation during functional tests, 2) unwillingness to cooperate and not to follow the rehabilitation protocol and, 3) receiving physiotherapy before enrollment. The ethics committee of Iran university of Medical Sciences approved the study (IR.IUMS.REC.1397.049).

Study procedure

A knee surgeon (ABF) referred participants diagnosed with isolated ACL deficiency to the first author (ZN). After explaining the study, eligible participants signed informed consent and entered the study. All participants received the same physiotherapy program for their involved side, consisting of 8 to 10 sessions of therapy to increase the knee range of motion, quadriceps, and hamstrings strength and reduce the edema and acute consequences of the injury (25). To ensure that the physical therapy protocol is the same for all cases, all the participants were treated in the same hospital's physical therapy ward.

After four weeks, the participants visited the Institute of Sports Sciences to perform isokinetic tests using a System 4 Pro Biodex dynamometer (Shirley, New York, USA). The correct sitting position of the participants in the Biodex machine was such that the axis of the knee was aligned with the mechanical axis of the dynamometer. The end of the machine lever arm was secured above the ankle with a strap, and the participant's torso was also fixed by the shoulder, back, and thigh straps (26). Before starting the test, gravity correction was performed after recording torque generated by each leg at 30 degrees of the knee flexion. To minimize interference from other muscles, the participant held their arms crossed over the chest (27). To assure the necessary confidence in performing tests, all tests were first performed on the healthy leg and then on the injured one.

The maximum voluntary isometric muscle contraction was first recorded in three repetitions. Then, 30 and 50 percent of maximum torque was calculated, which was considered as sub-maximal values. To test the maximum strength of the quadriceps muscle's voluntary contraction, the knee joint was fixed at a 60-degree flexion angle. Then we asked the person to contract his quadriceps muscle with maximum extension strength for seven seconds. Maximum muscle contraction was performed in three repetitions with a 30-second rest interval between repetitions. The maximum amount of the extension torque that could be retained constant for at least two seconds was determined as the maximum strength of the quadriceps muscle contraction (Fig. 1).

For this purpose, the computer screen was placed directly in front of the participant at a fixed distance of one meter. A horizontal line indicating the percentage required for the test was displayed on the screen. The participant was asked to apply a force to the lever attached to his limb toward the knee extension. The output torque reached the level specified on the screen and tried to keep the exerted force as constant as possible for at least seven seconds on the line displayed. The amount of force applied by the participant was displayed by a line with a distinct color, from right to left of the screen. The same process was repeated for the injured leg. To get acquainted with how to perform the test, at first, one test was performed without registration on the healthy side. The results of the next three repetitions were then recorded with a 30-second break between each repetition. The rest time between each test was two minutes (28).

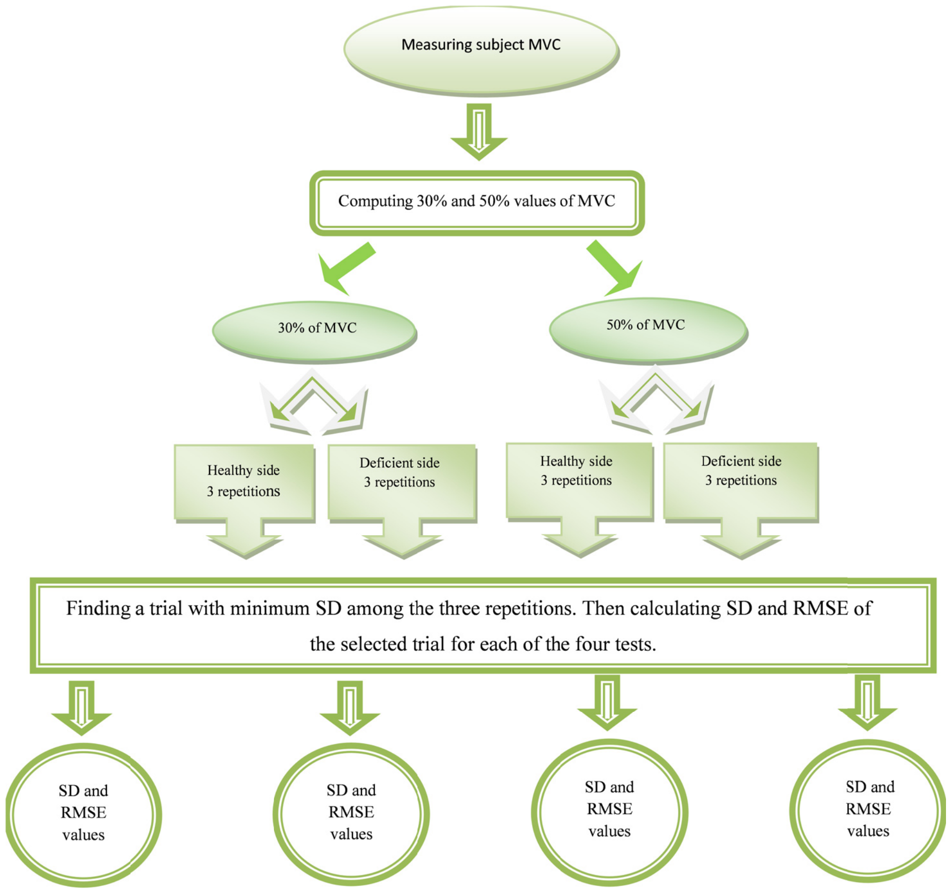

Fig. 1. Flowchart of the test process

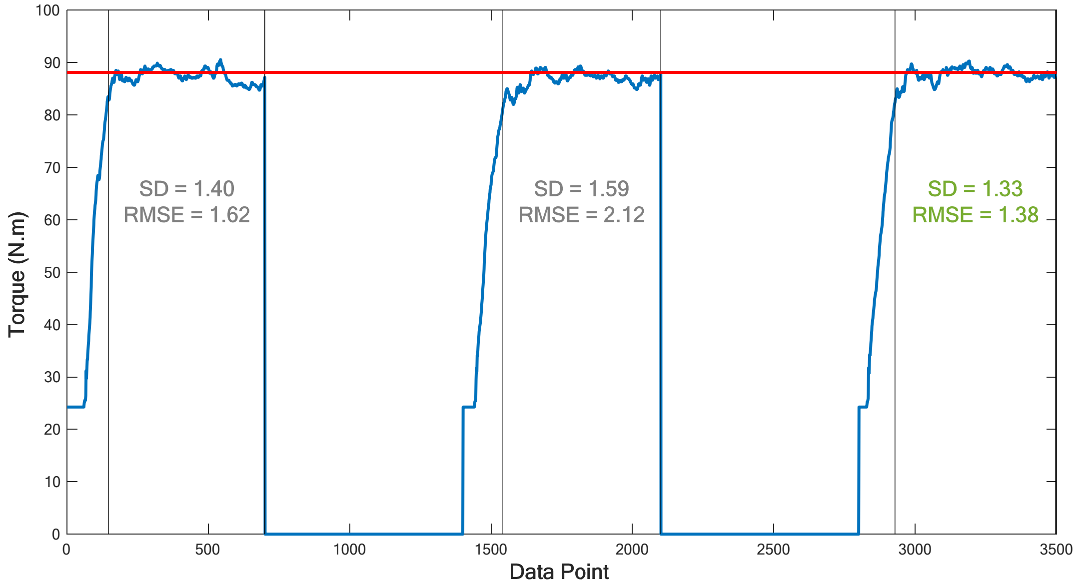

Fig. 2. Torque measurement of three trials of the healthy left knee of a participant. Vertical thin black lines depict the data window selected for each trial in which root mean square (RMSE) and standard deviations (SD) were calculated. The red line indicates the target value of 88N (50% of MVC=176N for this participant). The trial with the minimum SD (in this case, the last one) was chosen for further analysis.

Data Processing

Raw data were extracted from the Biodex machine as text files coded separately, including three repetitions in one file. Then, each test was plotted to be checked for possible missing data points or bad recording. The start and endpoints of cycles were visually determined (vertical black lines in Figure 2). The target line was computed as 0.3 or 0.5 of the MVC value (red line in Figure 2). The root means squared error (RMSE) of torques values (blue line, Figure 2) from the target values and the standard deviation (SD) of torque values were computed for every three cycles. The trial with a minimum SD value was selected and its RMSE and SD measures (in N.m) were considered for statistical analysis.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS 17) was used for data analysis. Shapiro-Wilk test was applied to assess the normality of data distribution. Some data were not normal; after logarithmic transformation, all distributions became normal. A two-way analysis of variance was employed to analyze SD and RMSE in two levels of MVC percentage (30% and 50%) for both sides. The statistical significance level was set at 0.05.

Results

In this observational cross-sectional study, 13 men (age: 27.85±7.04, BMI: 23.63±2.25) with acute unilateral ACL deficiency (48.08±21.32 days from injury) entered the study. A two-way analysis of variance was conducted to assess SD and RMSE (Table 1) of two levels of quadriceps contraction (30% of MVC, 50% of MVC) across both healthy and deficient knees of participants.

The two-way repeated-measures ANOVA for SD revealed a significant main effect for MVC percentage, F (1, 12) =19.13, p=0.001, partial eta squared (η_p^2) =0.61. SD of quadriceps torque in 50% of MVC (1.44±0.13) was higher than 30% of MVC (0.88±0.1).

In contrast, there was no significant main effect for a knee condition, p=0.152, η_p^2=0.16. SD of quadriceps torque was similar in healthy (1.3±0.15) and deficient knees (1.02±0.11).

There was no significant interaction between knee condition and MVC percentage, p=0.152, η_p^2=0.16.

Also, RMSE analysis showed a significant main effect for MVC percentage, p=0.003, partial eta squared=0.54. RMSE of quadriceps in 50% of MVC (2.41±0.29) was higher than 30% of MVC (1.36±0.21).

On the contrary, there was no significant main effect of

Table 1. Descriptive statistics of SD and RMSE (n=13)

Variables	SD	RMSE
	Mean± SD (N.m)	Mean± SD (N.m)
30% of MVC in healthy side	1.00±.55	1.55±1.05
30% of MVC in deficient side	.76±.35	1.17±.78
50% of MVC in healthy side	1.61±.63	2.56±1.33
50% of MVC in deficient side	1.28± .49	2.25±1.15

RMSE for knee condition, p=0.164, partial eta squared=0.155. RMSE of quadriceps were similar in healthy (2.06±0.27) and deficient knees (1.71±0.21).

There was no significant interaction between knee condition and MVC percentage for RMSE, p=0.573, partial eta squared=0.03.

Discussion

This study aimed to investigate the control of knee extension torque in the acute stage of ACL rupture at two levels of sub-maximal contraction on both healthy and injured sides. So the effect of damage (injury) on the neuromuscular function and possible differences between both sides were assessed. We hypothesized that the quadriceps muscles of the injured side have inadequate control and function compared to the healthy side and that the control is better in moderate activities. Due to the study's results, the control of knee extension torque in individuals with acute unilateral ACL rupture in the healthy leg was similar to the injured leg, and the rate of control was better in less intense activities.

One of the results of this study was that the steadiness and accuracy of the quadriceps muscle were better at 30% MVC than50%. It means neuromuscular control was better in mild activities. In people with ACL rupture, the less intense the activity, the better the control of the quadriceps muscle. So, in these people, by reducing the intensity of activity, we can have more control over the quadriceps muscle. Therefore, people with ACL rupture should avoid strenuous activities or change the type of their sport. A previous study has shown that the rate of re-injury and rupture of contralateral ACL is higher in high-impact activities (29) and has suggested that changing the level of sports activities and neuromuscular strengthening exercises help athletes avoid re-injury (30).

Another result of our study indicates that the quadriceps control's steadiness and accuracy are similar for the injured and uninjured sides. Because the control in the ACL rupture decreases compared to the healthy individuals (21), the similarity of the healthy side with the injured one means that the error in the healthy side has increased, and the steadiness has also decreased. Therefore, in strengthening and perturbation exercises, attention should also be paid to the healthy side because defects in the neuromuscular system cause more stress on passive structures such as ligaments and make them prone to rupture and injury (4). In line with it, Paterno, M.V. et al. (31) showed that the risk of ligament rupture in the contralateral side with ACL rupture even after ligament reconstruction surgery is three times higher than the operated side ,which shows the importance of strengthening the muscles and neuromuscular control of healthy side. In another study, it is stated that the possibility of re-rupture after ligament reconstruction surgery is 40% higher compared to a healthy person, and also the risk in the contralateral knee is twice as high as in the operated knee (32).

In addition to the limited sample size of this study, only individuals with isolated ACL rupture were evaluated, so the results cannot be generalized to all ACL rupture cases.

Conclusion

After the unilateral rupture of the ACL, the neuromuscular system becomes defective, and muscle control is then reduced in the healthy side. Therefore, the healthy side is also vulnerable to ligamentous damage. Besides, the more intense the activity, the less neuromuscular control and the greater the risk of injury. Therefore, in these individuals' rehabilitation programs, especially those who want to return to sport, quadriceps neuromuscular training should not be ignored on the healthy side. Moreover, due to the reduction of neuromuscular control on both sides, the healthy side in unilateral rupture cannot be used as a comparison criterion. It is also necessary to change the activity level and reduce its intensity to prevent the contralateral side's injury.

Acknowledgment

None

Ethics Approval

The study was approved by the ethics committee of Iran university of Medical Sciences (IR.IUMS.REC.1397.049) and was registered in registry of clinical trials (IRCT20181003041219N1).

Conflict of Interests

The authors declare that they have no competing interests.

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